

Project Title: Porphyry Copper Life Cycles

Statement of Problem

Arizona and adjacent areas of New Mexico and Sonora account for about 10% of world copper production. Within this copper-rich province, issues of urbanization, habitat preservation, and mining are becoming increasingly important. Studies of porphyry copper deposits, their regional geologic and geochemical context, and economic and production history will have a significant positive impact on land-use planning, mineral development, and environmental issues.

The commodity life cycle starts with the formation of deposits, which may subsequently be eroded or mined. The cycle continues through refining, utilization, and natural and anthropogenic recycling. All these aspects can be viewed conceptually in terms of identifying cycles and determining their associated fluxes (Figure 1, available at <http://www.geo.Arizona.edu/cmr/PCLCPfigs.html>).

With a few notable exceptions (e.g. Titley, 2001; Lang and Titley, 1998), past studies of porphyry copper systems in Arizona and adjacent parts of New Mexico and Sonora have focused on individual deposits or districts at map and temporal scales appropriate only to the deposit in question. In this project, we propose to work simultaneously at three principal map scales: province, regions (clusters of mining districts), and deposits, with an emphasis on the provincial and regional scales.

The provincial and regional components of investigation are necessary to resolve many scientific questions and to provide the societal context. Indeed, many of the collaborating groups (e.g., other USGS projects, Arizona Geological Survey) fundamentally employ a regional approach. The provincial and regional components should yield a better understanding of the context in which the deposits occur, as well as expand the scope of scientific and societal problems to which the project can contribute. All cycles have implicit temporal scales. Wilson cycles and the crustal evolution of a porphyry copper province operate on time scales of tens of millions to billions of years, and orogenic events persist for millions to tens of millions of years. Individual mining districts typically have cycles of discovery, development, mining, and closure of a few years to hundreds of years. Metallurgical processing cycles and meteorological events that significantly affect mines operate on time scales that range from a few hours to a few months. Hence, the choice of appropriate time scales is as important as the choice of map scales when approaching life cycle problems.

An integrated approach that employs a range of spatial and temporal scales is most likely to yield breakthroughs in understanding problems of porphyry copper life cycles.

Objectives

Our objective is to contribute not only to a better understanding of the economic geology of porphyry copper deposits, but also to regional geologic and geochemical processes that have the potential to be of long-term societal interest. Expected products include syntheses of the tectonic history and crustal evolution of the region, improved regional geochemical baselines, better models of porphyry copper deposits, a new set of occurrence models for exotic

copper deposits, and an analysis of the technological and socioeconomic factors at each historic stage of mining life cycles and their implications for changes in mineral resource, ore reserve, water resource, land use, and environmental management issues. These products will provide the scientific background and baselines that are required for technically sound, well-informed choices regarding land use planning, health, and environmental issues, and mineral development.

Relevance and Impact

Mining of porphyry copper deposits has made a significant contribution to civilization's age of electricity, and it appears that it will continue during the silicon age. Porphyry copper mining also is a globally significant human activity from a flux standpoint, as the annual total mass flux from porphyry copper mining is comparable to the annual total all of arc volcanism (Figure 2 <<http://www.geo.Arizona.edu/cmr/PCLCPfigs.html>>).

The Laramide porphyry copper province of southwestern North America extends from Arizona into adjacent parts of New Mexico and Sonora. The 300-km-long Arizona urban corridor, which extends from Phoenix to Nogales, lies wholly within the principal copper metallogenic province of the United States. Arizona accounts for about 65% of total U.S. copper production and value, and about 7% of global production. Mexican production adds another 3%, making a global total of about 10% for the entire province. Total reserves for this region as a percentage of world porphyry copper reserves are Cu 20%, Mo 14%, Ag 4%, Au 9%, Pb 5%, and Zn 10%. Since World War II, southern Arizona has become increasingly urbanized, and metropolitan areas have encroached on lands once used primarily for mining, farming, and grazing.

Arizona has a number of active mines, mines on stand-by, and several undeveloped deposits. Resource assessments done in the region by the USGS and state agencies indicate a high probability that other minable deposits await discovery. Some mines and parts of districts have been exhausted and present the typical range of post-mining environmental issues. Active mines present some of the same environmental issues as closed mines. Mining, extraction, and refining techniques for undeveloped deposits are certain to be different from present practices and present challenges that involve significant geological aspects.

Foremost among the undeveloped deposits is the recent discovery of the Magma Porphyry (now called Resolution) deposit in the Superior district (Manske and Paul, 2002), which lies within one of the regions that will be studied in this project. The history of the district typifies the cyclical component in copper mining life cycles. The Superior district was founded in the 19th century, and there were several major expansions, modernizations, and closures, but the first ore-grade intercept in the deep, blind Resolution deposit was not until 1995. This deposit is unusual and important for a number of reasons. Chief among them, however, is that Resolution is almost certainly the porphyry deposit with the highest hypogene copper grades ever discovered in Arizona, more than 100 years after mining began in the area and almost a half-century after intensive modern exploration began.

The potential for scientific discovery from an integrated study of this province is comparable to the potential economic importance of the recent discovery of the Resolution deposit, and we expect the impact to extend well beyond an understanding of the economic geology of the deposits to the geology and crustal evolution of the entire region. An integrated study of this porphyry copper

province will benefit land-use planning, mineral development, and environmental assessment.

Strategy and Approach

The collaborative aspects of the proposed five-year cooperative project were broadened and strengthened and the focus sharpened during the feasibility period. Integration of the various aspects of the project is the key to success in understanding cycles and determining the associated fluxes. Integration and collaboration will be promoted by taking a matrix approach to operation, with scales of investigation cutting across task boundaries, and by sharing people across boundaries between tasks and study sites.

The project team will work simultaneously at three scales of investigation: province scale; regional scale (focus starting in the Ray-Globe-Miami-Superior area, but branching out over time to the Sierrita-Tucson Basin and Safford-Morenci areas); and deposit scale (Ray at first and then shifting to Dos Pobres and possibly other deposits). The methodologies are organized into five tasks that cut across the scales of investigation and sites: (1) Mesozoic and Cenozoic crustal framework, (2) regional distribution of chemical elements, (3) characteristics and evolution of hydrothermal systems, (4) dispersion and concentration of materials from porphyry copper and related deposits in the region, and (5) historic life-cycle analysis of porphyry copper exploration and mining.

Task 1 will produce a stepwise series of palinspastic restorations from present day to initiation of the Laramide arc and orogeny. The task will improve the understanding of Tertiary extensional structure and tectonics of the province, which affect the distribution and exposure/preservation of Laramide rocks, and will contribute to the understanding of Laramide magmatism and structure. Task 1 provides the means for converting surficial distributions of rocks and corresponding geochemical analyses into volumes of rocks and geochemical fluxes, and the task is the basis for extrapolating results obtained at individual regions and deposits to the rest of the province.

Task 2 will provide geochemical insights from the geologic understanding gained in Tasks 1 and 3, as the geochemical analyses obtained in Task 2 are the means to quantify fluxes of components. Although geochemical mass transfer studies of deposits are well known to economic geologists, this task is a novel attempt to extend the methodology to regional and provincial scales and to erosion and sedimentation as a function of time over 80 m.y.

Because the tilted and dismembered areas within the province provide system-scale exposures, Task 3 will identify the deposit-scale cycles and fluxes and contribute to the understanding of the roots, caps, and sides of hydrothermal systems and to the gradients within them. It will also investigate possible genetic relations between some Laramide porphyry and mid-Tertiary deposits.

Task 4 examines dispersion and concentration of components. Task 4 will likely lead to breakthroughs in understanding the supergene environment as it evaluates the competing roles of physical and chemical dispersion in forming exotic copper deposits. By gaining a better understanding of these natural processes and addressing surface and near-surface cycles and associated fluxes, the task will provide an improved context for addressing environmental issues.

Task 5 focuses on the historical portion of the porphyry copper life cycle and

its economic consequences. This task translates geologic and geochemical findings into consequences for mining and processing, and its materials flows are the civilization-scale cycles and associated fluxes.

The extent of collaboration and the magnitude of work completed to date on the project, as enumerated in the task narratives, demonstrate that the expected results are attainable.

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